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Research Article

Effects of bamboo leaf ash on alkali-silica reaction in concrete

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ABSTRACT

The construction industry is generally faced with so many challenges of which deterioration in concrete structures caused by Alkali-silica reaction (ASR) is one of the pressing challenges. This reaction induces expansion in concrete, resulting in its eventual cracking and subsequent failure. Research direction is being geared towards obtaining properties of pozzolanic concrete of recently discovered different biogenic pozzolans such as bamboo leaf ash (BLA). BLA has been proven to be acceptable in terms of compressive strength and some other properties but few researches have been performed on the impacts of ASR on BLA concrete structures. This research work focuses on investigating the properties of BLA through X-ray diffraction and fluorescence analyses, and its effectiveness in resisting or eliminating ASR that may be present in concrete. Tests were performed on concrete bars soaked in NaOH at a temperature of 80 °C to determine the possible reactivity of aggregates to ASR. In addition, workability and the compressive strengths of BLA concrete at different percentage levels were determined after curing for 7, 28 and 56 days. The findings of the research show that BLA improves the workability of fresh concrete, however, it causes a decline in the compressive strength of concrete when compared with the strength of conventional concrete. Also, BLA has no detrimental effect on the linear expansion of concrete. This study recommends that a 5% partial replacement of cement with BLA will give effective performance when used in areas where strength is not the major priority.

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1. INTRODUCTION

Durability, high fire resistance, low cost, and low maintenance associated with concrete have contributed immensely to its wide acceptability worldwide [1]. However, concrete deterioration can occur when concrete is exposed to aggressive environmental conditions [2]. Alkali-silica reaction is one of the main causes of concrete deterioration due to its detrimental influence on the durability of concrete structures [3]. For instance, the deleterious features of the ASR in concrete are cracking, expansion and misalignment of structural elements, and spalling of concrete's surface [4].

Also referred to as concrete cancer, ASR occurs in concrete structures as a result of the availability of alkalis in concrete's pore solution, calcium hydroxide in a free state, high PH, reactive silica (amorphous) in aggregates and sufficient moisture to drive the reaction [5]. At high PH, the hydroxyl ions of sodium and potassium alkalis existing in concrete's pore solution react with and cause the reactive amorphous silica in aggregates to dissolve [6]. This dissolved silica reacts with free calcium (Ca^{2+}) ions from calcium hydroxide (obtained from the hydration process between cement and water) to form a gel-like material around the aggregates and within the concrete pores [7, 8]. Figure 1 shows a schematic diagram of the mechanisms involved in the Alkali-silica reaction in concrete.

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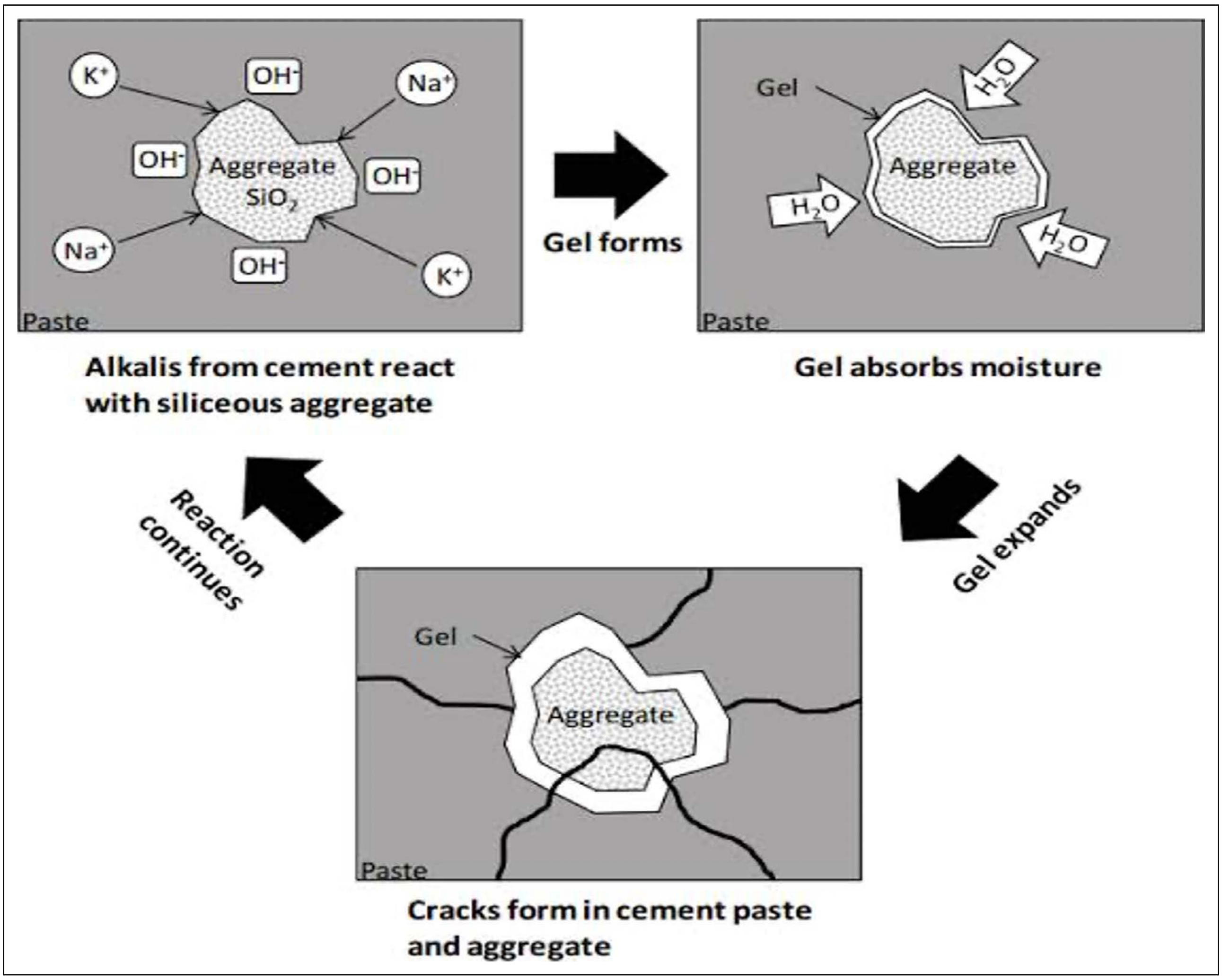

Figure 1. Diagram showing Alkali-silica reaction mechanism in concrete. Source: [10].

This gel, referred to as Alkali-silica gel, is rich in silica, alkalis and other ions. In addition, ASR gel is hygroscopic. Expansion occurs when this gel absorbs water and enlarges in size, then it exerts pressure in the concrete; when this pressure exceeds the tensile capacity of concrete, cracking occurs. The development of cracks in the concrete increases the inflow of moisture, causing an iterative process that exposes the concrete to more expansion. This ultimately causes spalling and strength loss in concrete [6, 9, 8]. If this reaction is not checked, it can further lead to the corrosion of reinforced steel and sulphate attacks [4] thereby reducing the serviceable life of the concrete [7].

ASR occurs in concrete in two major stages:

First stage:

Reactive silica+alkali+moisture→ASR gel

$SiO_2+2KOH+H_2O \rightarrow K_2SiO_3.2H_2O$

(2KOH can be replaced by 2NaOH)

Second stage:

ASR gel+moisture→Expansion

A lot of strategies have been put in place to lessen the development of ASR in concrete. Among such strategies include limiting concrete's alkali content using low alkali cement, applying chemical admixtures such as lithium compounds, using non-reactive aggregates and incorporating pozzolanic materials in concrete [11, 12]. This study, however, focuses on the use of pozzolans in curtailing ASR in concrete. This is because pozzolanic materials improve the concrete's resistance to ASR by reducing calcium hydroxide ($Ca(OH)_2$) and the spreading of ions in concrete [13].

Pozzolanic materials are artificially or naturally-occurring materials that contain reactive amorphous aluminosiliceous and siliceous materials [14]. They have the characteristics of reacting with alkali in the presence of moisture and in a fine form to form cementing compounds [15]. Silica, present in pozzolans reacts with calcium hydroxide, $Ca(OH)_2$ found in concrete's pore solution to form calcium silicate hydrate and other cementing compounds [16–18]. The production of calcium silicate hydrate in concrete is effective in binding alkalies and thus mitigating ASR in concrete.

The chemical representation of the pozzolanic reaction is given below:

$3Ca(OH)_2+2SiO_2=3CaO.2SiO_2.3H_2O$

$3Ca(OH)_2+Al_2O_3+3H_2O=3CaO.Al_2O_3.6H_2O$

Other properties discovered in the use of pozzolans are lower permeability and higher strength [19]; influence on the rate of bleeding and segregation, the heat of hydration and setting time, water demand and workability of concrete [20].

The reactivity of pozzolans, whether naturally obtained or artificially obtained, depends largely on their degree of fineness, the amorphousness of their structures and the content of their aluminum, iron and silicon oxides. While investigating the influence of fly ash on Alkali-silica reaction, [21] clarified that the effectiveness of fly ash in inhibiting ASR majorly depends on the replacement level than the degree of fineness. The study of [22] attributed the high pozzolanic reactivity of artificial pozzolans such as fly ash, metakaolin and silica fume to their high concentrations of soluble reactive SiO_2.

This finding was also similar to that of [23] when they assessed the effect of four kinds of pozzolans – blast-furnace slag, natural pozzolan, silica fume and siliceous coal fly ash – on Alkali-silica reaction elimination in concrete. Based on their findings, the mortars containing cement-pozzolan blends exhibited lower open porosities when compared with the control mortars. However, only coal fly ash and silica fume were more effective in curbing Alkali-silica reaction in concrete while blast-furnace slag and natural pozzolan require higher replacement level of at least 30% to effectively curb Alkali-silica expansion. The study of [24] clarified the higher efficiency of silica fume in mitigating Alkali-silica reaction over fly ash. They attributed silica fume's effectiveness to its porous surface which causes it to absorb more alkalis than fly ash. Concrete is more durable and resistant to Alkali-silica reaction when the replacement level of silica fume is within 7 to 10% [23–25].

The research findings of [26] proved that metakaolin significantly decreased the concentration of calcium hydroxide present in mortars. Due to its low calcium content, it reduces the calcium-to-silicon ratio, thereby increasing concrete's resistance to Alkali-silica reaction [27]. Further studies by [28] opined that the 20% of metakaolin present in concrete can effectively reduce about 89% of the expansion caused by Alkali-silica reaction. Metakaolin also improves the compressive strength of mortar. The findings of the research conducted by [29] revealed that there was an increase in the compressive strength of mortar with an increasing amount of metakaolin. However, the optimal strength was obtained when the replacement level of metakaolin is within the range of 5 and 10%.

Although industrial by-products such as silica fume and fly ash are often used as cementitious materials to replace cement partially in concrete, however, due to the possible decrease in their production in the future and limited availability in developing countries, researchers are now tilting towards investigating the potential of agricultural wastes such as bamboo leaf ash, rice hush ask, palm oil fuel ash, and sugarcane bagasse ash in influencing concrete's durability and mechanical properties [30].

Studied how bamboo leaf ash affects concrete's mechanical properties [31]. They found that the incorporation of bamboo leaf ash makes concrete more impermeable, thus reducing water absorption. However, an increase in the replacement level of bamboo leaf ash in concrete led to a decrease in the compressive and tensile splitting strengths of the concrete. Although the optimum replacement level of bamboo leaf ash in the concrete is 10% when compressive strength is considered while it is 20% for tensile splitting strength. Bamboo leaf ash also influences the setting time and heat development in concrete. The research findings of [32] pointed out that concrete containing cement-bamboo leaf ash blends have setting times higher than that of conventional concrete, thereby lowering heat development in mass concrete.

Likewise, studies have been made to investigate the ability of rice husk ash to act as a supplementary cementitious material. Obtained by burning rice husk at 800 °C, its high silica content and specific surface area contribute to its high reactivity [30, 33]. Rice husk ash with finer particles have higher pozzolanic reactivity and are much more potent in preventing ASR in concrete than those with coarser particles [34–35]. The partial replacement of cement with fine rice husk ask makes the concrete mix more impermeable, thus reducing the percolation of alkalis in the concrete [36]. [2]'s review of literature on how Alkali-silica reaction can be mitigated in concrete revealed that rice husk ash is more effective when the replacement level is 40%.

To determine the effectiveness of these pozzolans to inhibit Alkali-silica reaction in concrete, it is imperative to determine the alkali silica reaction of these pozzolans as it will be of further help in knowing the expansion ability of each pozzolanic material. This research, therefore, investigated the effect of BLA on ASR.

2. MATERIALS AND METHODS

Materials used in this research are BLA, clean water for mixing and curing, Ordinary Portland Cement (Dangote type), granite and sand as coarse and fine aggregate respectively.

2.1. Raw Materials

Bamboo leaves were collected from the main bamboo trees and dried. BLA was obtained by burning the dried bamboo leaves at a temperature of about 600 °C for 1 h based on the optimum temperature from past researchers [37]. It was then sieved using a 75 μm sieve to increase the surface area needed for the reaction.

2.2. Mixing Ratio and Curing Conditions

A mix ratio of 1:2:4 of cement to sand and coarse aggregates respectively was used. The water-cement ratio used was 0.65. The concrete cubes were cured by immersing them in clean water at a temperature of 27 °C for a period of 7, 28 and 56 days.

2.3. Test Methods

Particle size distribution analysis, moisture content test and specific gravity test were carried out on the sand. The aggregate crushing value (ACV) test and aggregate impact value (AIV) test were carried out on granite. X-ray diffraction analysis and X-ray fluorescence analysis were performed to determine the chemical composition and pozzolanic reactivity of BLA. Compressive strength and accelerated mortar-bar tests were performed on concrete samples to determine the strength of concrete and the potential alkali-silica reactivity of aggregates respectively. Cement was partially replaced by BLA in levels of 0%, 5%, 10%, 15%, 20% and 25% respectively by weight. For each percentage replacement, three concrete cubic specimens were produced.

2.3.1. Test Methods Applied to Aggregates

Particle size distribution analysis: Sieve analysis to assess the distribution of the particle sizes of the soil sample was performed per [38]. A quantity of soil sample was weighed and dried in the oven at a temperature of about 110 °C. The dried sample was poured into a set of sieves. The sieve at the top has the largest mesh size and each lower sieve in the column has a smaller mesh size than the one above it. At the base of the column was a round pan used to collect particles with sizes lesser than 75 μm. This set of sieves was manually shaken for some minutes. The sample retained on each sieve was weighed after the shaking was completed. The percentage passing and the percentage retained on each sieve were calculated. The outcomes were presented as a graph of percentage passing against the sieve size on a semi-logarithmic graph.

Moisture content test: The moisture content test was carried out in accordance with [39] to determine the total amount of water present in the soil sample.

A container and its lid were clean, dried and weighed (M1). A portion of the test portion was placed in the container and then weighed (M2). This was heated at a steady temperature of about 110 °C in the oven for a duration of 16 to 24 h. The container was then taken out of the oven, allowed to cool, and weighed once more (M3). The moisture content of the sample was calculated as:

$$\text{Moisture content} = \frac{M2-M3}{M3-M1}\ x\ 100\%$$

Specific gravity test: Specific gravity gives the ratio of the mass of the soil to the mass of the standard reference, which is water.

Three density bottles with stoppers were cleaned, dried, and weighed. Their masses were recorded as W1. Small amounts of oven-dried soil samples were put into the bottles and their weights were taken and recorded as W2. The bottles were then completely filled with water and left for 24 h. After this, their weights were taken and recorded as W3. The bottles were emptied, thoroughly cleaned and filled with water. The weights were taken and recorded as W4.

The specific gravity of the soil sample was calculated as:

$$\text{The specific gravity of soil} = \frac{W2-W1}{(W4-W1)-(W3-W2)}$$

Aggregate crushing value test: To assess the aggregate's resistance to crushing under a gradually applied compressive load, the aggregate crushing value test was performed in accordance with [40].

12 mm aggregates were dried in an oven for about 4 h at a temperature of 110 °C. Three equal layers of the specimen were placed within the cylinder, and each layer received 25 tamping strokes from the tamping rod. The plunger was inserted so that it rested horizontally on the levelled surface of the aggregate. The apparatus was placed inside the universal testing machine along with the test specimen and plunger. The specimen was loaded at a uniform rate till the aggregates were crushed. The load was removed and the crushed material was poured on a clean tray of known mass. The weight of the tray and the aggregate were measured and recorded as M1. The whole specimen on the tray was sieved on the 2.36 mm test sieve and the weight of the fractions that passed through the sieve was recorded as M2. The aggregate crushing value was calculated as:

$$\text{ACV} = \frac{M2}{M1}\ x\ 100\%$$

Aggregate impact value test: The aggregate impact value test was carried out in accordance with [41] to determine the aggregate's resistance to sudden impact.

Aggregates of size 12 mm sieve were oven-dried at a temperature of about 110 °C for 4 h and cooled before testing. The aggregates were placed inside the steel cup and then compacted by applying twenty-five strokes of the tamping rod to it. The steel cup was fixed to the base of the impact testing machine and the hammer, which is at a position 380 mm above the upper surface of the cup, was made to fall freely on the aggregates 15 times. The crushed aggregate was poured on a clean tray of known mass. The weight of the tray and the aggregate were measured and recorded as M1. The whole specimen on the tray was sieved on the 2.36 mm test sieve and the weight of the fractions that passed through the sieve was recorded as M2.

The aggregate impact value was calculated as:

$$\text{AIV} = \frac{M2}{M1}\ x\ 100\%$$

2.1.2. Test Methods Applied to Bamboo Leaf Ash

X-ray diffraction analysis: The structural characterization of BLA was determined using an X-ray powder diffractometer. In a cathode ray tube, X-rays were produced, collimated, and directed at the sample. Every crystal has atoms that are arranged in a periodic arrangement, which allows them to diffract light. The arrangement of these atoms in the sample is revealed by the diffraction pattern that is created when X-rays are scattered from these atoms. The X-ray detector captured the reflected X-rays' strength. When the geometry of the incident X-rays colliding with the sample fulfils Bragg's equation, constructive interference and peak in intensity occur. This equation indicates the relationship between the diffraction angle, lattice spacing and wavelength of the electromagnetic radiation. The diffraction pattern produced by the diffractometer is compared with standard patterns to identify the crystalline form of BLA.

X-ray fluorescence analysis: The chemical and elemental composition of BLA was examined using an energy dispersive X-ray fluorescence spectrometer. BLA placed in an appropriate sample tray was exposed to high-energy X-rays from a controlled X-ray tube, which resulted in the emission of distinctive secondary X-rays. The detector selected these distinctive X-rays and produced a spectrum, which serves as a visual depiction of the sample's composition. This allowed for the determination of the sample's elemental analysis and oxide composition, which were then printed.

2.1.3. Test Methods Applied to Bamboo Leaf Ash-Based Concrete

Compressive strength test: Compressive strength of concrete is the ability of concrete to support loads on its surface without crack or deflection. It is dependent on the quality of concrete material, strength of Portland cement, water-cement ratio, etc. This test can either be carried out in a cube or a cylinder.

Concrete specimens of 150 mm x 150 mm x 150 mm sizes were produced by replacing cement partially with BLA at 5%, 10%, 15%, 20% and 25% levels. The specimens were cured for 7, 28 and 56 days' duration at a temperature of 27 °C. The compressive strength was carried out in conformity with [42].

It should be noted that three cubic specimens were prepared for the control specimens and specimens containing partial replacement of cement.

Potential alkali reactivity of aggregates: This test method provides a means of detecting the potential of an aggregate to undergo an ASR within 16 days. The test was carried out per [43].

Portland cement, sand and granite were mixed in a ratio of 1:2:4 to form mortar. Two test specimens were made for the control and each cement-BLA combination. Molds made according to [44] specifications were filled with mortar in two equal layers. After this, the molds were placed in a moist cabinet or room for the next 24 h. The specimens were removed from the molds, and the initial comparatory readings were made. The specimens were then immersed in tap water inside a storage container, and placed in an oven at a temperature of about 80 °C for 24 h. After this, the specimens were removed, dried and the zero readings were taken. Later, the specimens were immersed in Sodium Hydroxide inside the storage container. The container was sealed and placed in an oven at a temperature of 80 °C. Subsequent comparator readings of the specimens were taken at 7, 28 and 56 days to check for variations in the lengths of the concrete specimens. The difference between the zero reading of the specimen and the comparator reading at each period was calculated and recorded as the expansion of the specimen for that period.

3. RESULTS AND DISCUSSION

3.1. Properties of Aggregates

The particle size distribution analysis of the soil sample shown in Figure 2 indicates that the soil sample has a coefficient of uniformity of 3.33 and a coefficient of curvature of 0.83. This implies that the soil sample is uniformly graded [45]. Table 1 shows the overall moisture content of the soil sample to be 8.4%. Since the moisture content is less than 15%, the soil sample is dry soil. The specific gravity of the soil sample is 2.70 (Table 2) and this indicates that the soil sample is silt [46].

The aggregate crushing value of granite used as the coarse aggregate in concrete is 28.6% as shown in Table 3. Since this value is less than the maximum attainable value of 30%, it shows that coarse aggregate is a good material in the production of concrete [40]. Also, the aggregate impact value of granite shown in Table 4 is 19.4%, showing that the granite is strong and capable of resisting suddenly applied loads [41, 47].

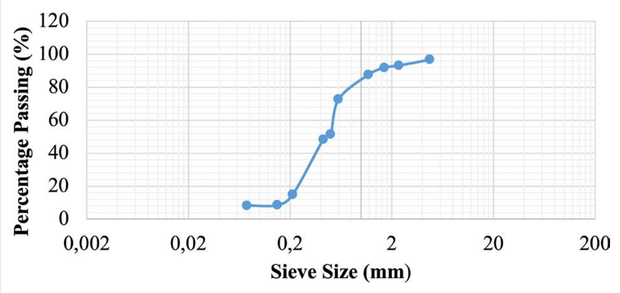

Figure 2. Particle size distribution curve for soil sample.

Table 1. Moisture content of soil sample

	Sample 1	Sample 2	Sample 3
Weight of container, M1 (g)	24.8	24.5	25.6
Weight of container+wet soil, M2 (g)	116.0	99.2	110.0
Weight of container+dry soil, M3 (g)	109.2	93.1	103.6
Moisture content (%)	8.1	8.9	8.2
Average moisture content (%)		8.4	

Table 2. Specific gravity of soil sample

	Sample 1	Sample 2	Sample 3
Weight of empty bottle, W1 (g)	284.3	292.4	322.3
Weight of bottle+dry soil, W2 (g)	299.2	307.1	337.8
Weight of bottle+soil+water, W3 (g)	576.8	571.6	586.7
Weight of bottle+water, W4 (g)	566.4	562.7	578.1
Specific gravity	3.31	2.53	2.25
Average specific gravity		2.70	

Table 3. Aggregate crushing value of granite

Aggregate	Sample 1 (%)	Sample 2 (%)	Sample 3 (%)	Average (%)
Granite	30.8	28.6	26.5	28.6

Table 4. Aggregate impact value of granite

Aggregate	Sample 1 (%)	Sample 2 (%)	Sample 3 (%)	Average
Granite	17.9	19.2	21.1	19.4

3.2. Properties of Bamboo Leaf Ash

The X-ray diffraction analysis of BLA shown in Figure 3 shows that the minerals in BLA are tridymite (a stable form of SiO_2), graphite, garnet (a silicate mineral), illite, lime (calcium oxide), periclase (magnesium mineral) and hanksite.

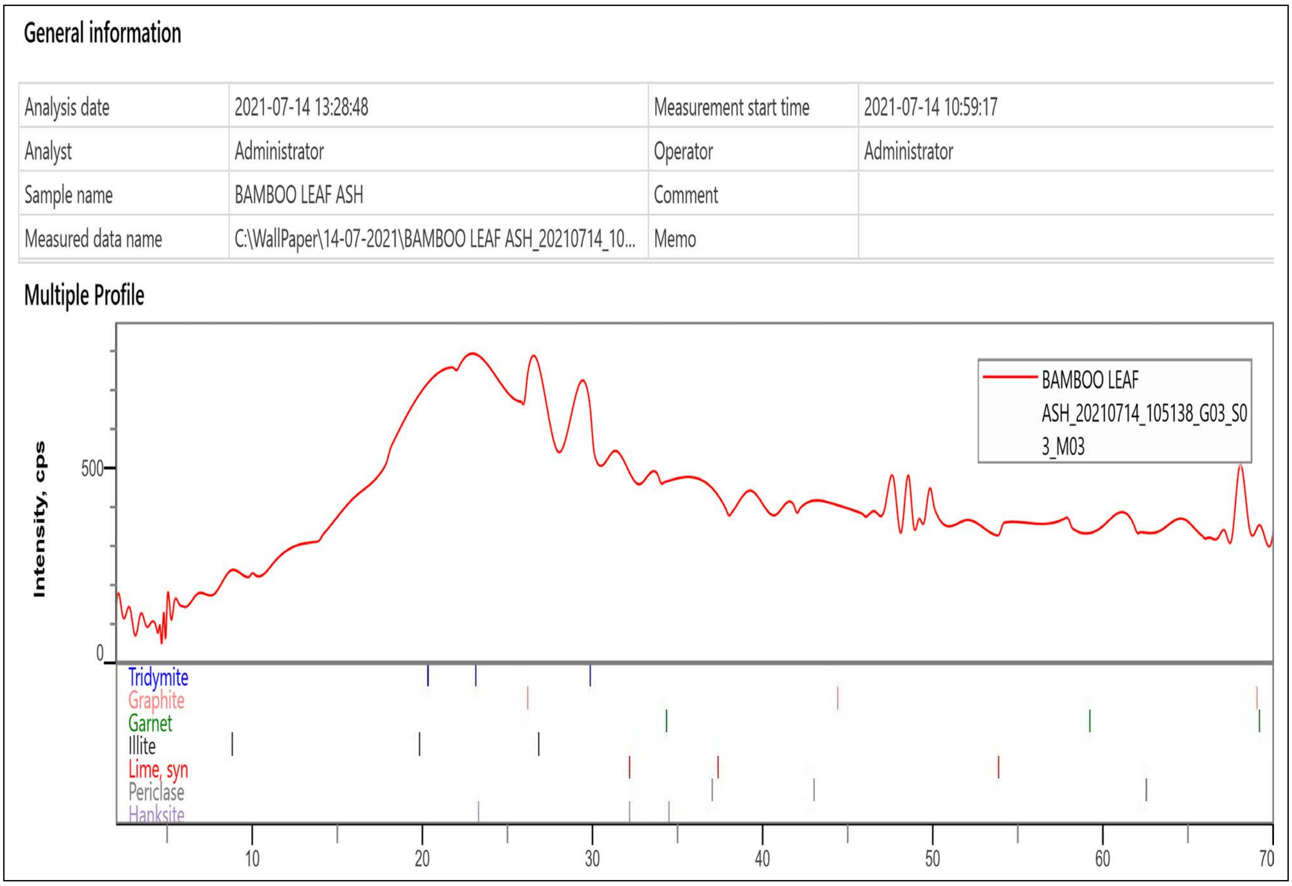

Figure 3. A pattern showing the compounds present in BLA and their intensities.

Table 5. Major required oxides of bamboo leaf ash

Constituent	Composition (%)
Aluminum oxide (Al_2O_3)	2.96
Calcium oxide (CaO)	16.26
Ferrous oxide (Fe_2O_3)	3.98
Magnesium oxide (MgO)	0.00
Potassium oxide (K_2O)	6.37
Silica (SiO_2)	64.81

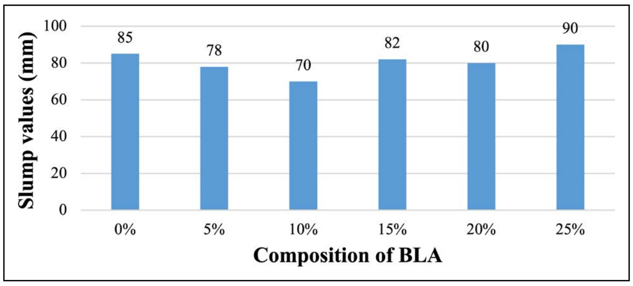

Figure 4. Effect of bamboo leaf ash (BLA) on the workability of fresh concrete.

The result of the X-ray fluorescence analysis of BLA shown in Table 5 reveals that the combination of Silica (SiO_2), Aluminum Oxide (Al_2O_3) and Iron Oxide (Fe_2O_3) present in the BLA is 71.75%. This is greater than 70%, the minimum required before a material can be considered a pozzolan. Therefore, BLA is a pozzolan of Class N [48].

3.3. Effects of Bamboo Leaf Ash on the Properties of Concrete

This section discusses the effect of BLA on the workability, compressive strength and linear expansion of concrete.

3.3.1 Workability of Fresh Concrete

The slump values of the concrete presented in Figure 4 show that the fresh concrete has medium workability which is typically used for normal reinforced concrete placed with vibration.

3.3.2. Compressive Strength of Concrete

The result in Figure 5 shows the variations in the compressive strengths of the control concrete and each bamboo leaf ash-based concrete. The strength of the control specimen has attained 59.5% of the 28-day expected concrete strength after 7 days of curing while that of 5% BLA-based concrete has attained 46.5% of the 28-day expected concrete strength. Reduction in strength was recorded as the percentage replacement of BLA increases. This is an indication of a lower hydration rate of BLA concrete samples. The same trend was recorded for 28-day and 56-day compressive strengths of the concrete.

In conclusion, the incorporation of BLA has a negative impact on the compressive strength of the concrete. The general overview shown in Figure 5, indicates that

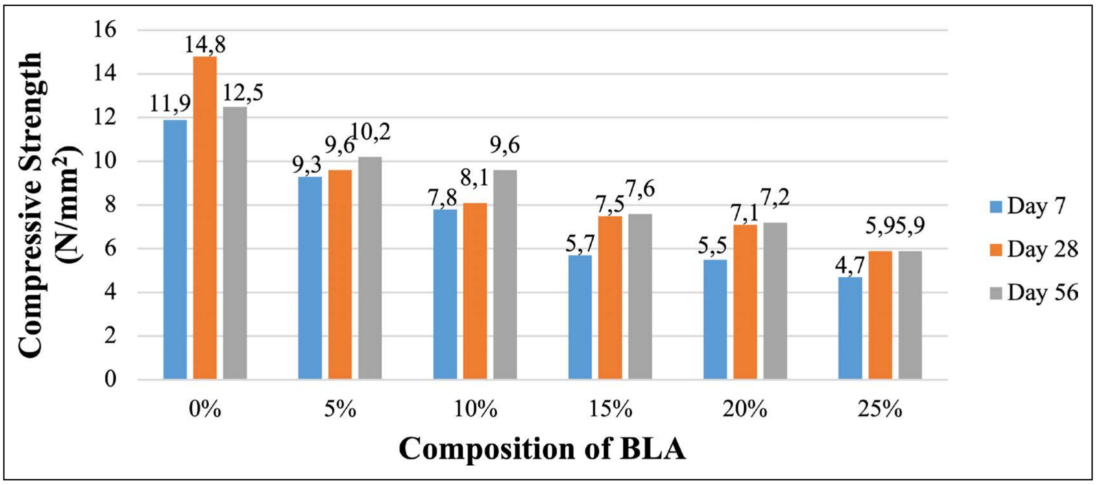

Figure 5. A graph showing the comparison of the average compressive strengths of concrete at 7, 28 and 56 days against the composition of BLA in cement.

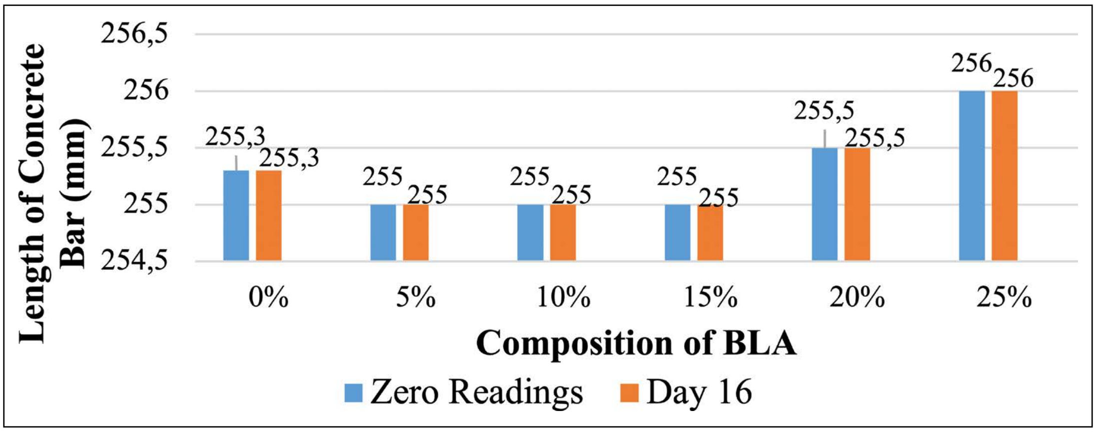

Figure 6. A graph showing the comparison of the zero readings and Length of concrete bars on day 16.

concrete specimens with cement-BLA combinations have lesser strengths when compared to the control specimens i.e. the conventional concrete. This corroborated the study of [49] which establishes that concretes containing natural pozzolans have lower strengths when compared with conventional concretes.

3.3.3. Linear Expansion of the Concrete Bar

The initial reading of each concrete bar is approximately 255 mm and Figure 6 shows a comparison between the zero readings and the length of concrete bars after being placed in Sodium Hydroxide solution at a temperature of 80 °C. There was no difference in the length of the bars after the zero readings were taken and after 16 days of being immersed in sodium hydroxide solution. From this, it can be deduced that the incorporation of BLA in concrete causes the concrete to be at low risk of deleterious expansion when used under field conditions [43].

3.4. Comparison of the Study with Previous Studies

The findings of this study, regarding the silica content, workability, and compressive strength of the concrete, including the optimal content value of bamboo leaf ash are compared with those obtained in previous studies shown in Table 6.

The silica content of the bamboo leaf ash used in this study was 64.8% and this value is less than the ones obtained in five studies. This difference can be attributed to possible inconsistencies in the temperature at which bamboo leaves were calcined. The study of [50] established a correlation between the suitability of calcining temperature of BLA and the silicon oxide content.

Based on past literatures, bamboo leaf ash causes a decrease in the workability of concrete. The increase in workability of BLA-cement blend concrete against the control concrete can be attributed to the high water-cement ratio used in the study. This is consistent with the research findings of [51] that proved that concrete's workability increases with increasing water-cement ratio.

In conclusion, based on the correlation between this research and previous research works, it can be deduced that the incorporation of bamboo leaf ash in concrete reduces the compressive strength of concrete. However, in construction works where durability and sustainability are the main focus, and not compressive strength, 5 to 10% of cement can be replaced with bamboo leaf ash.

Table 6. Effects of bamboo leaf ash on concrete in past literatures

Authors	Silica content (%)	Compressive strength (N/mm²)	Slump value (mm)	Optimal value (%)
[37]	53.00	Concrete with BLA-cement blend has higher strength than that of control.	–	8
[50]	72.81	There was a decrease in the strength of BLA-cement concrete as the proportion of BLA increases. However, the strength of BLA-cement concrete at optimum value for BLA was higher than that of the control concrete after 56 days of curing.	–	5
[52]	75.69	Reduction in compressive strength of BLA-cement blend concrete with increasing concentration of BLA.	Reduction of workability by 5.5%.	5
[53]	75.90	Reduction in compressive strength of BLA-cement blend concrete with increasing concentration of BLA.	Increase in the BLA content in concrete leads to decrease in workability.	10
[54]	65.66	An increase in the content of BLA led to a decrease of the compressive strength of BLA-cement blend concrete.	There was a decrease in concrete's workability as the proportion of BLA increased.	5–10
[55]	72.78	There was a decrease in the compressive strength of BLA-cement blend concrete with an increase in the concentration of BLA.	The higher the proportion of BLA in concrete, the lower the workability.	5
[56]	75.10	Reduction in compressive strength of BLA-cement blend concrete with increasing concentration of BLA, especially at early ages.	Increase in the concentration of BLA causes increase in workability.	10

4. CONCLUSION AND RECOMMENDATIONS

Based on the findings of this research, the following conclusions can be derived;

a. Bamboo leaf ash can be used in construction (especially weak concrete zones like German floors or blinding) where high concrete strength is not a priority.
b. The use of bamboo leaves in the production of bamboo leaf ash is a means to reduce waste in the environment.
c. Bamboo leaf ash has no detrimental effect on the linear expansion of concrete. Concretes containing BLA are at low risk of expansion caused by ASR if they are to be used in real construction.

This research recommends that to achieve optimum strength in concrete, a five per cent partial replacement of cement with BLA should be used. Also, the use of locally-available materials should be encouraged in the Nigerian construction industry to promote environmental sustainability.

ETHICS

There are no ethical issues with the publication of this manuscript.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declare that they have no conflict of interest.

FINANCIAL DISCLOSURE

The authors declared that this study has received no financial support.

PEER-REVIEW

Externally peer-reviewed.

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